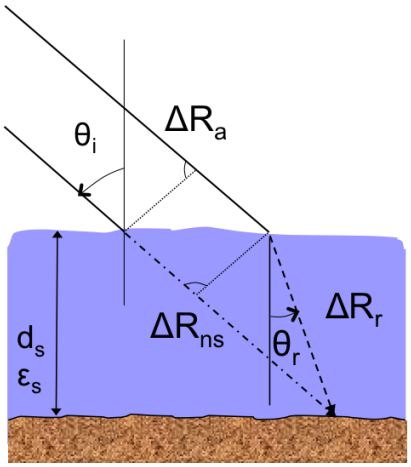
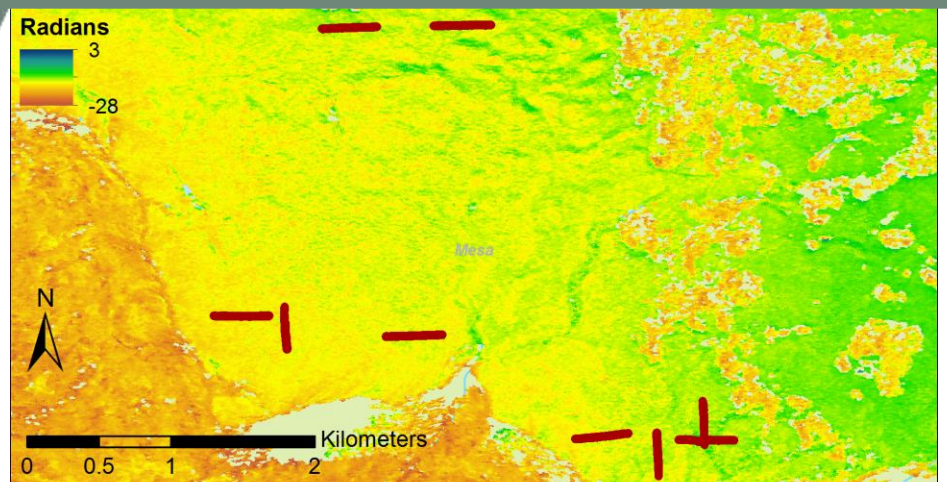
Supporting NASA SnowEx: L-Band Interferometric Snow Depth and SWE Estimation

Elias Deeb[1], HP Marshall, Richard Forster, Cathleen Jones, Christopher Hiemstra, and Paul Siqueira

[1]Cold Regions Research and Engineering Lab (CRREL)
US Army Corps of Engineers (USACE)
Engineering Research and Development Center (ERDC)
Hanover, NH

SnowEx Workshop, Longmont, CO
8 August 2017





US Army Corps of Engineers

CRREL

NASA JPL

BOISE STATE UNIVERSITY

THE UNIVERSITY OF UTAH

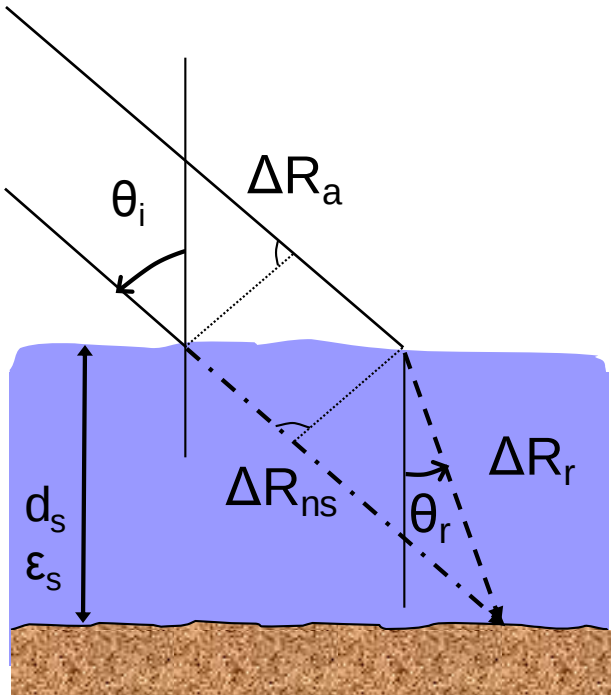
UMASS AMHERST

NASA SnowEx

How much water is stored in the Earth's terrestrial snow-covered regions?

- Multi-year (FY17 – FY21) **field and airborne snow campaign** designed to validate sensor data with a goal to identify **future snow satellite mission**
- Using a combination of remote sensing, models, and ground-based measurements
- Feb 2017 field campaign
  - Grand Mesa and Silverton, CO
  - 3-week field campaign
  - International snow community
  - Over 100 participants

Radar propagation in dry snow



(modified from Guneriussen et al., 2001)

ΔR_{ns} = Path length without snow
θ_i = Incidence angle

d_s = Snow depth
ε_s = Permittivity

ΔR_a = Path length through atmosphere
ΔR_r = Path length refracted through snow
θ_r = Refracted radar angle

Phase shift due to snow:

$$j_{snow} = -\frac{4\rho}{l_i} d_s \left(\cos q_i - \sqrt{e_s' - \sin q_i^2} \right)$$

Snow Water Equivalent (SWE)

- Water yielded when melting a volume of snow
- Depth * density (integrated) through the snowpack

Phase shift due to snow:

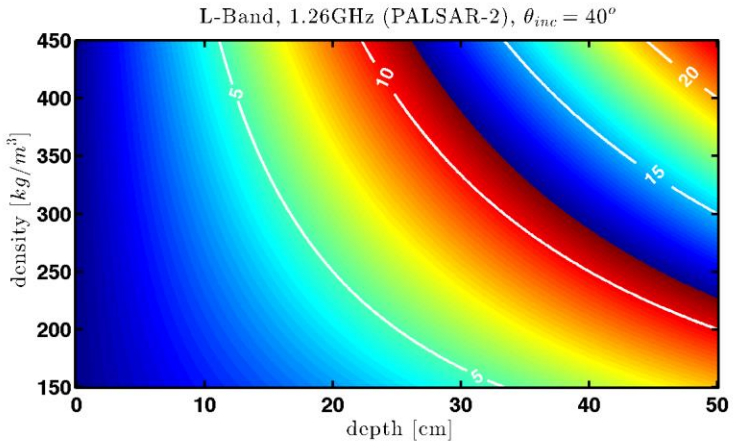
$$j_{snow} = -\frac{4p}{l_i} d_s \left(\cos q_i - \sqrt{e_s' - \sin q_i^2} \right)$$

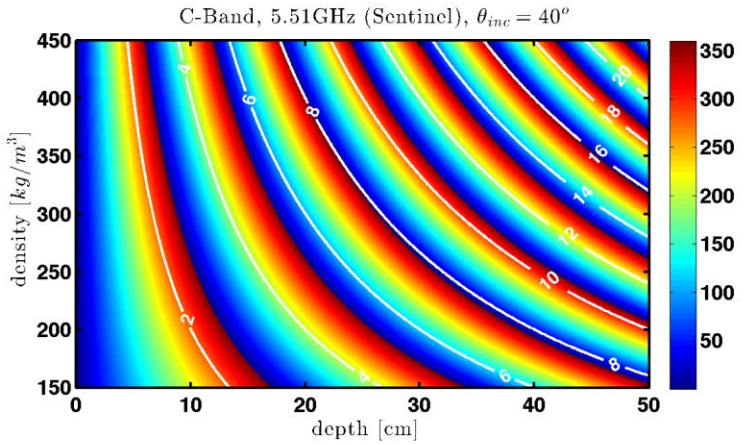
$$j_{snow} \sim d_s * e_s' = \Delta SWE$$

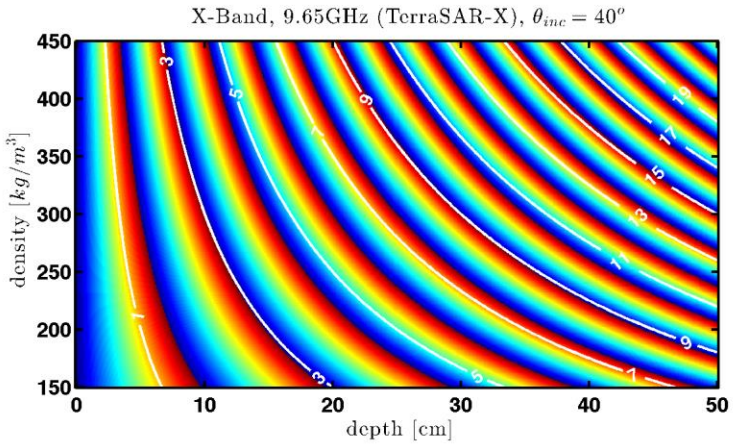
Guneriussen et al., 2001

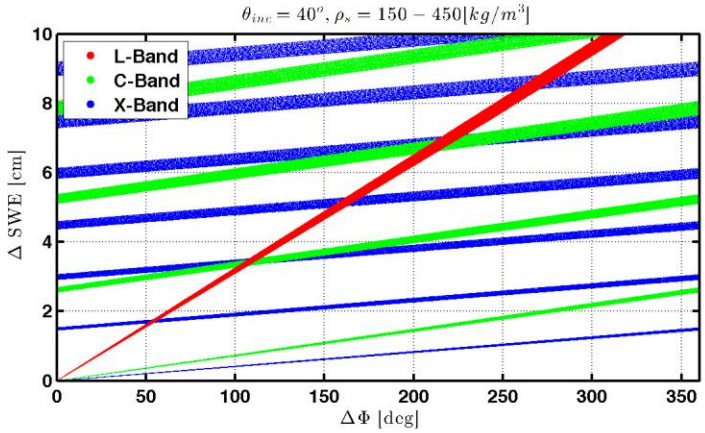
Modeling Phase Change: ΔSWE

If majority of the signal is from the snow-ground interface, phase change depends only on density/depth, due to refraction & velocity changes.



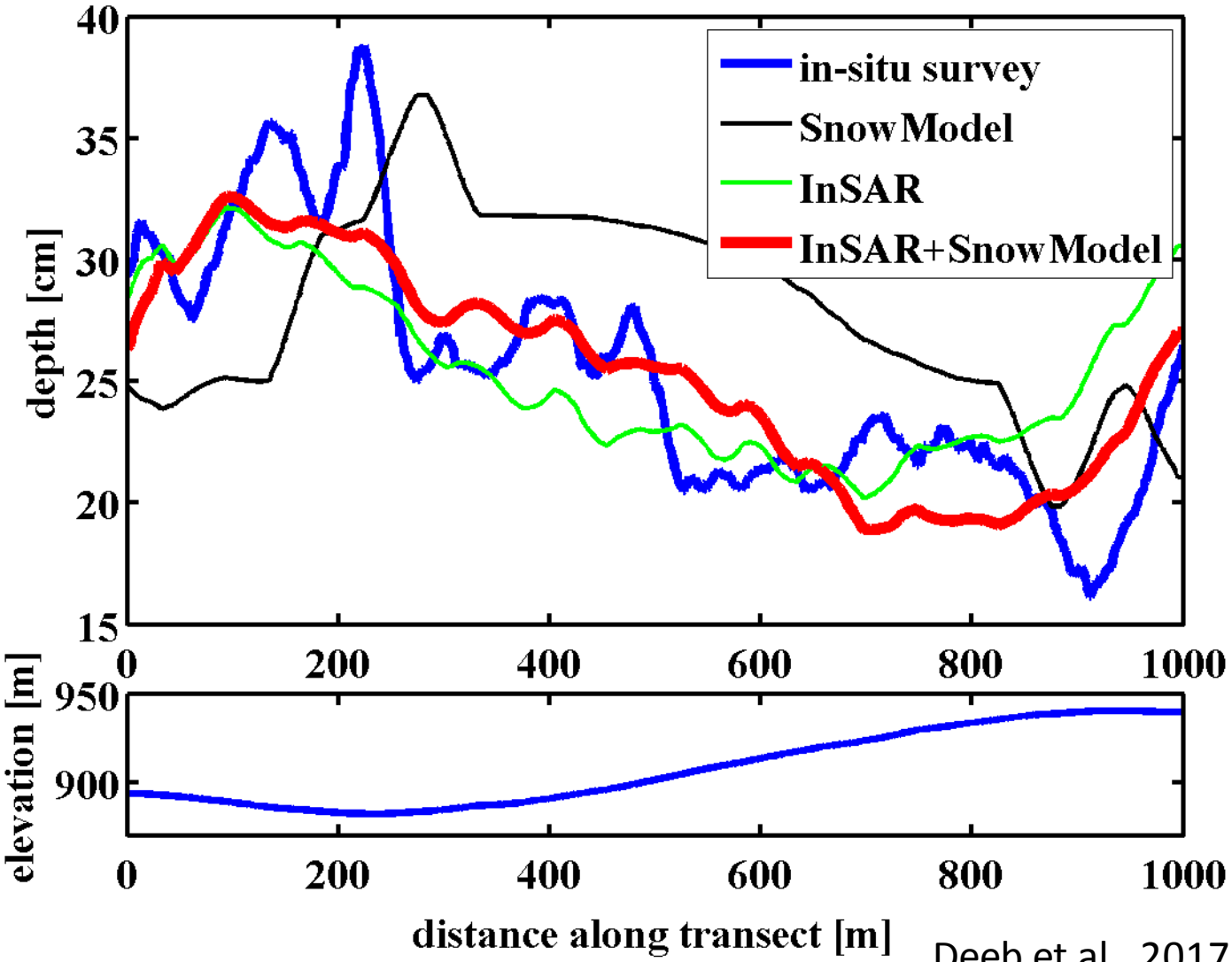




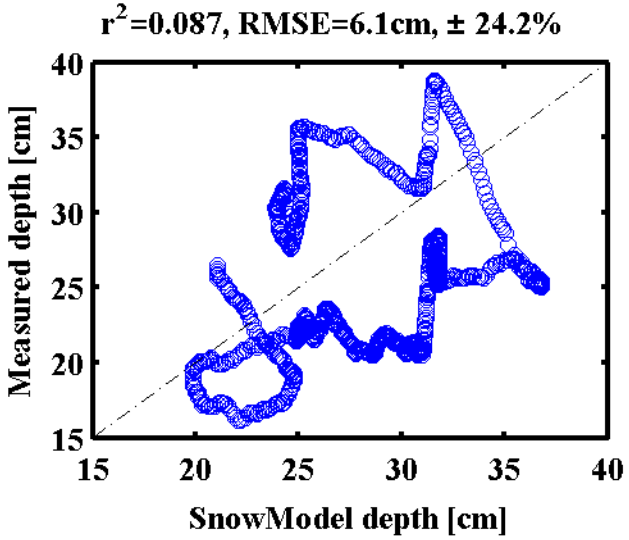


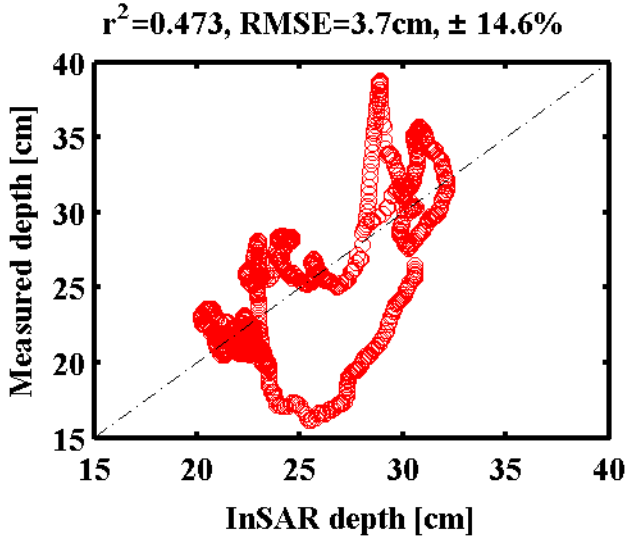
Based on Grubler and Hiller, 1974; Ulaby et al., 1980; Matzler, 1996; Guneriussen et al., 2001

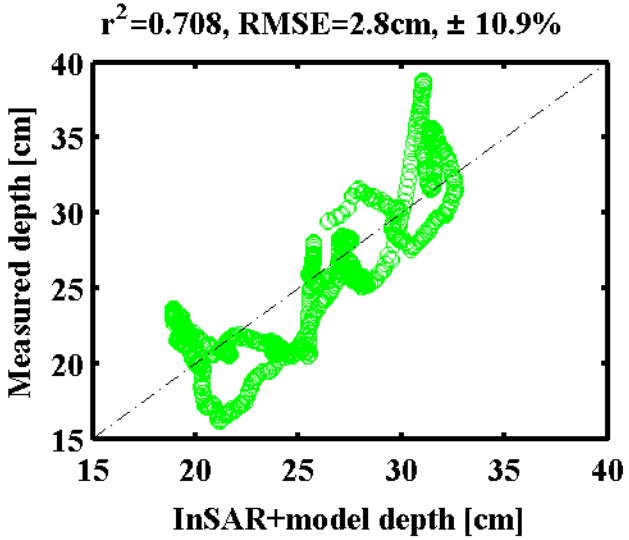
L-Band InSAR (PALSAR)
Imnavait Creek transect, Alaska

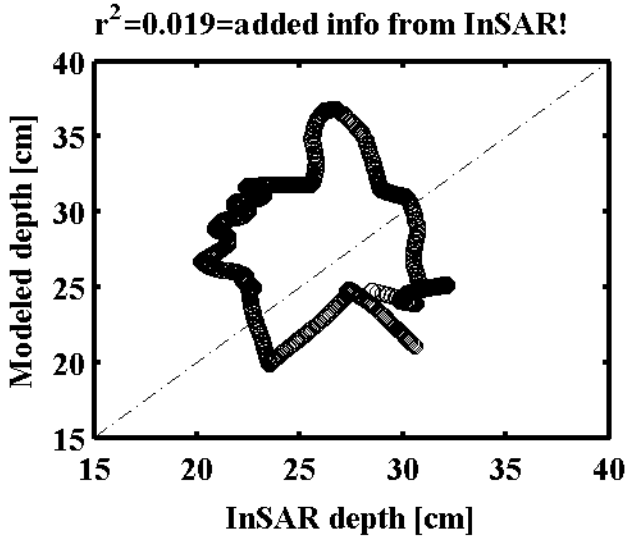


Deeb et al., 2017, submitted


r²=0.087, RMSE=6.1cm, ± 24.2%
Measured depth [cm]
SnowModel depth [cm]
15
20
25
30
35
40


r²=0.473, RMSE=3.7cm, ± 14.6%
Measured depth [cm]
InSAR depth [cm]
15
20
25
30
35
40


r²=0.708, RMSE=2.8cm, ± 10.9%
Measured depth [cm]
InSAR+model depth [cm]
15
20
25
30
35
40


r²=0.019=added info from InSAR!
Modeled depth [cm]
InSAR depth [cm]
15
20
25
30
35
40

NASA-ISRO SAR Mission (NISAR)

- US and Indian, dedicated InSAR mission
- Level 1 Science requirements
  - Earth surface displacements, sea ice, vegetation biomass, cropland and vegetation biomass, natural and anthropogenic disasters
- Team is part of SDT (snow hydro) applications
- L-Band (23cm) and S-Band (12cm)
- 12-day (or shorter) exact repeat orbit
- 3-10 meter resolution
- Launch date: 2020

https://nisar.jpl.nasa.gov

Airborne InSAR platforms

- UAVSAR – http://uavsar.jpl.nasa.gov
  - L-Band (1 GHz/23 cm) interferometer
  - Gulfstream-III (G3)

- Microwave Remote Sensing Lab, University of Massachusetts, Amherst
  - S-Band (2 GHz/15 cm) and Ka-Band (26 GHz/1 cm) interferometers
  - Mounted on Cessna door

SnowEx (Feb 2017) UAVSAR Support

Flight Plan Report: edeeb33_0008 (SnowEx FY17 (Feb) UAVSAR)

Created by edeeb33 on Sep 20, 2016 at 1:06 PM. Estimated flight time: 4 hrs 18 min.

Comments: Grand Mesa and Senator Beck Basin

Related Plans | **Plan Summary** | Flight Map (with KML files) | Flight Request | Configuration

Takeoff Airport (KPMD)	0 min	0 km
Transit to Line edee02_000aa	1 hr 21 min total 1 hr 36 min	1,003 km total 1,003 km
1. Line **edee02_000aa**	7 min 1 hr 43 min	96 km 1,099 km
Transit to Line edee02_000ab	12 min 1 hr 55 min	96 km 1,195 km
2. Line **edee02_000ab**	7 min 2 hrs 2 min	96 km 1,291 km
Transit to Line edee03_270aa	12 min 2 hrs 14 min	94 km 1,385 km
3. Line **edee03_270aa**	10 min 2 hrs 24 min	131 km 1,516 km
Transit to Line edee03_270aa	15 min 2 hrs 39 min	131 km 1,647 km
4. Line **edee03_270aa**	10 min 2 hrs 49 min	131 km 1,777 km
Transit to Landing	1 hr 29 min 4 hrs 18 min	978 km 2,755 km
Landing Airport (KPMD)	4 hrs 18 min	2,755 km

If you need to estimate costs for using UAVSAR:

NASA approved investigation (i.e. ROSES):

Estimated cost for this flight plan is **$13K**

▶ Plus any mission peculiar costs.

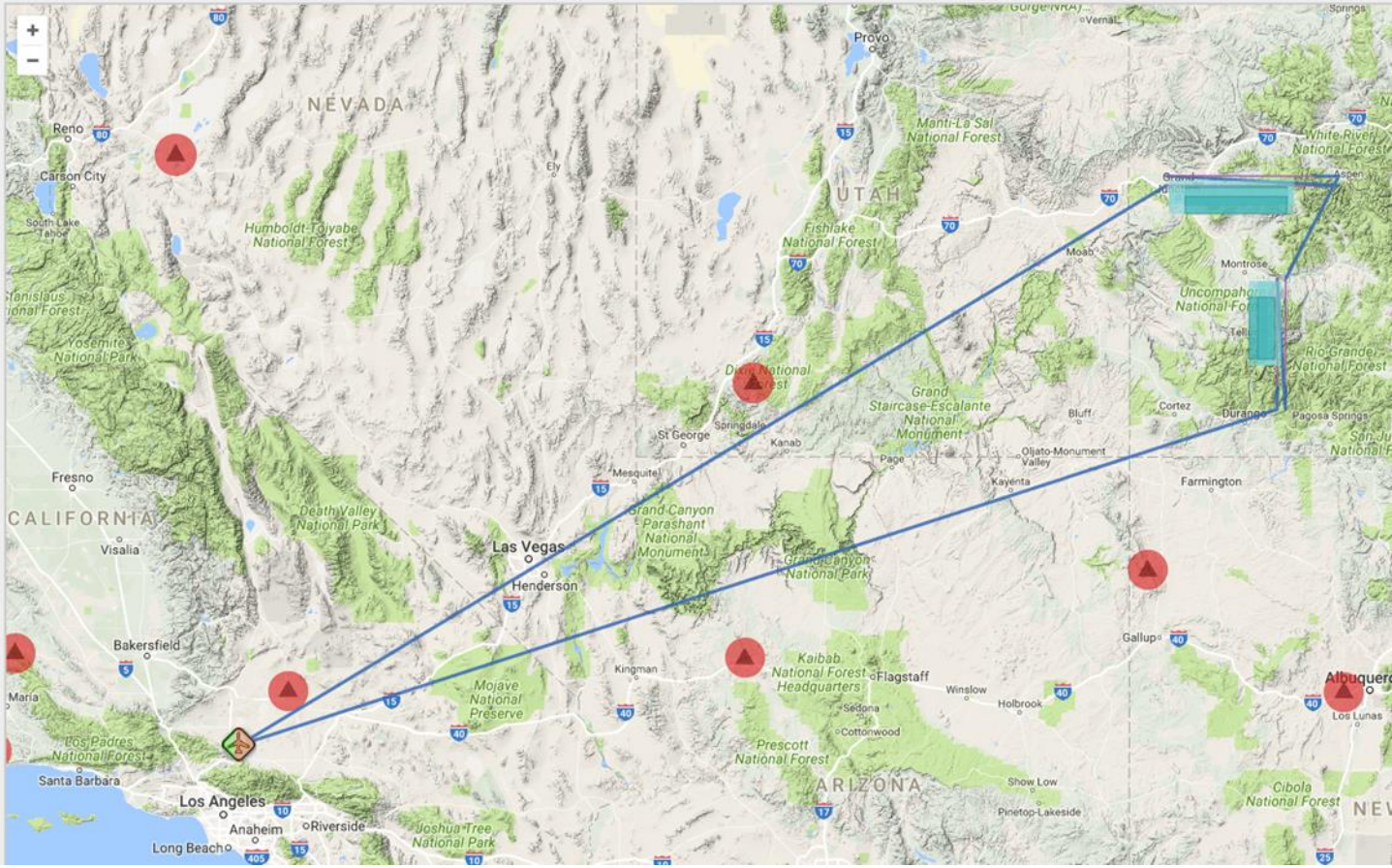
Based on $3000 per flight hour.

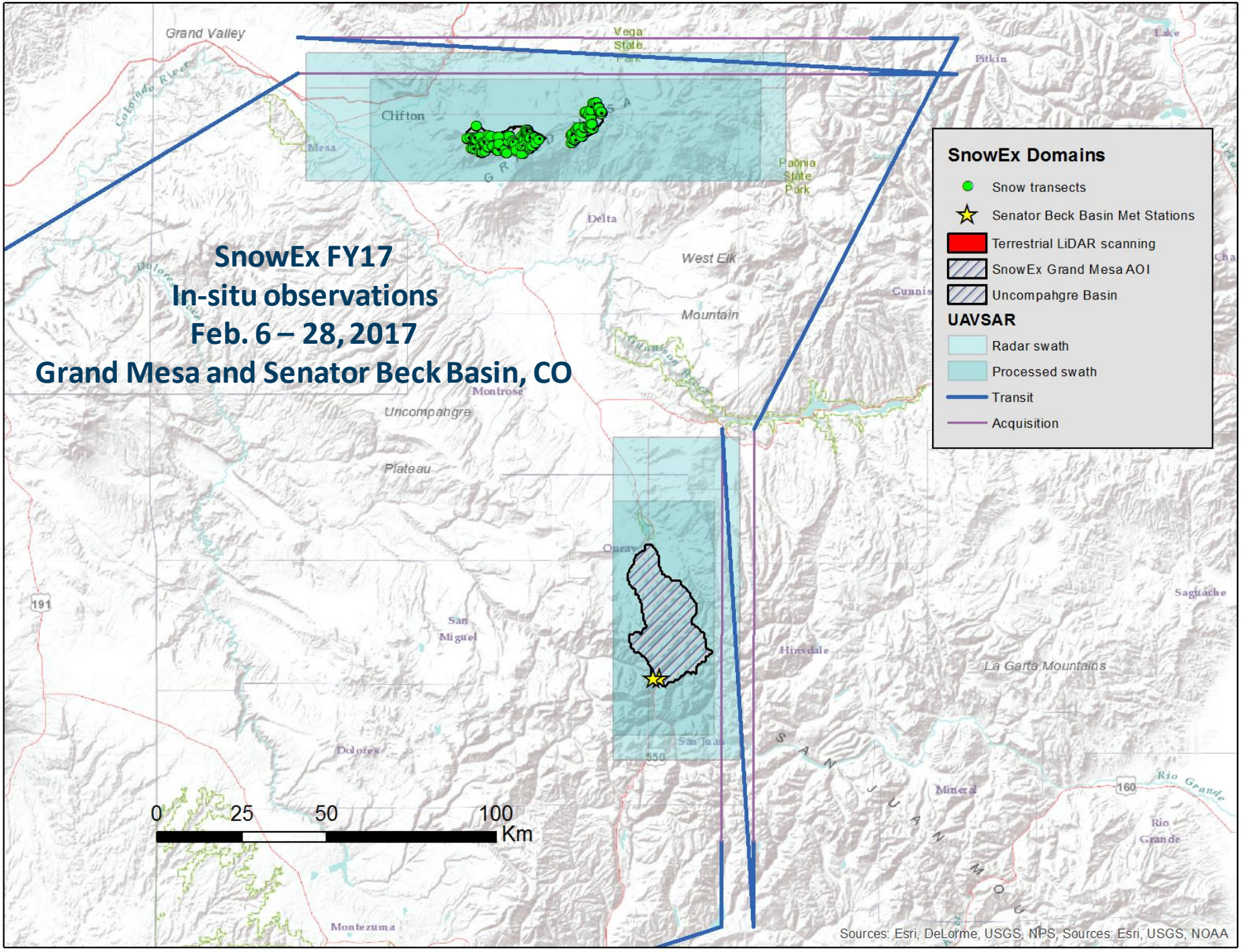
Non-NASA investigation (with NASA concurrence):

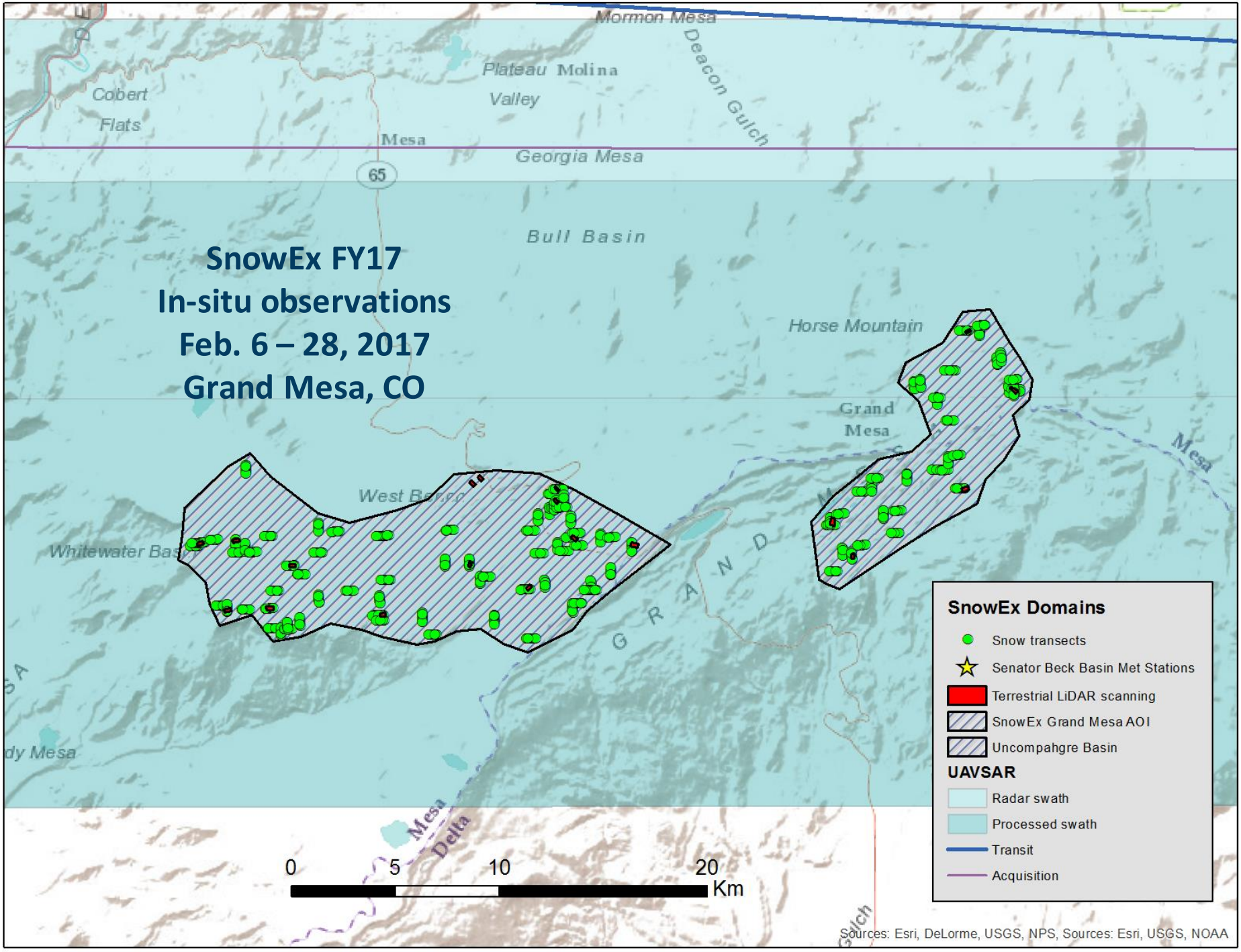
Estimated cost for this flight plan is **$47K**

▶ Plus any mission peculiar costs.

Based on $6000 per flight hour for aircraft operations, and $5000 per flight hour for instrument support and data processing.



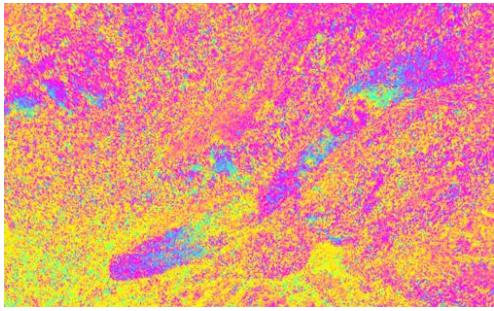

SnowEx FY17
In-situ observations
Feb. 6 – 28, 2017
Grand Mesa and Senator Beck Basin, CO
SnowEx Domains
Snow transects
Senator Beck Basin Met Stations
Terrestrial LiDAR scanning
SnowEx Grand Mesa AOI
Uncompahgre Basin
UAVSAR
Radar swath
Processed swath
Transit
Acquisition
Grand Valley
Vega State Park
Clifton
Mesa
Paonia State Park
Delta
West Elk
Mountain
Montrose
Uncompahgre
Plateau
Ouray
San Miguel
Hinsdale
La Garita Mountains
Saguache
Dolores
San Juan
Mineral
Rio Grande
Montezuma
0 25 50 100 Km
Sources: Esri, DeLorme, USGS, NPS; Sources: Esri, USGS, NOAA


SnowEx FY17
In-situ observations
Feb. 6 – 28, 2017
Grand Mesa, CO
Mormon Mesa
Deacon Gulch
Plateau Molina
Valley
Cobert
Flats
Mesa
Georgia Mesa
65
Bull Basin
Horse Mountain
Grand
Mesa
West Bo
Whitewater Ba
GRAND
Mesa
Mesa
Delta
dy Mesa
0
5
10
20
Km
SnowEx Domains
Snow transects
Senator Beck Basin Met Stations
Terrestrial LiDAR scanning
SnowEx Grand Mesa AOI
Uncompahgre Basin
UAVSAR
Radar swath
Processed swath
Transit
Acquisition
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

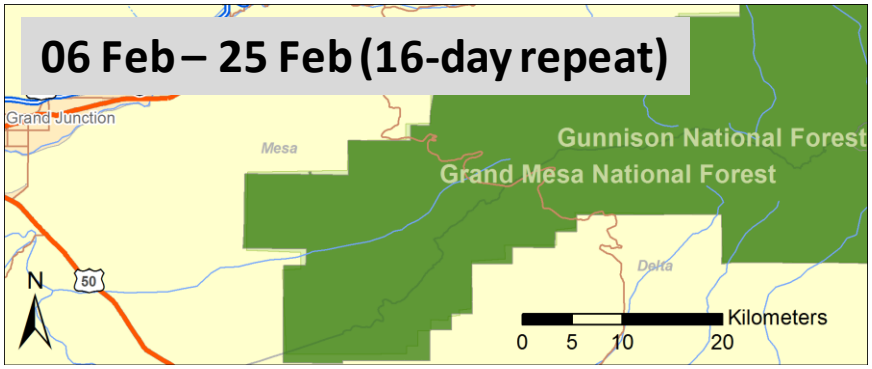
UAVSAR SnowEx Acquisitions

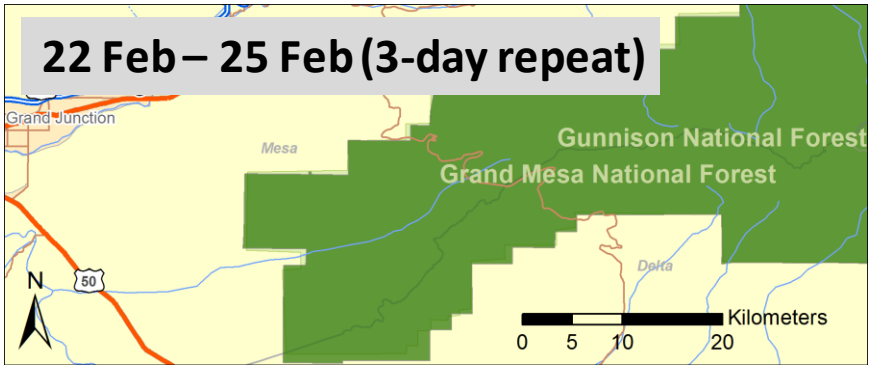
- Three acquisition dates and two AOIs:
  - ► 06 Feb, 22 Feb, and 25 Feb (during SnowEx)
  - ► Grand Mesa and Uncompaghre Basin
- Slumgullion slide path (NISAR SDT request)
  - ► Additional acquisitions: 8 Mar and 31 Mar
- UAVSAR products:
  - ► Amplitude (backscatter) for each acquisition date
  - ► InSAR products based on acquisition pairs
    - Coherence and phase (difference)

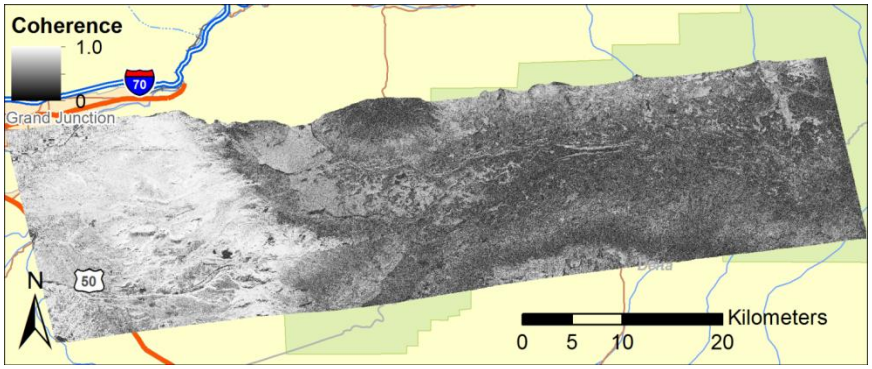
06 Feb – 22 Feb 2017

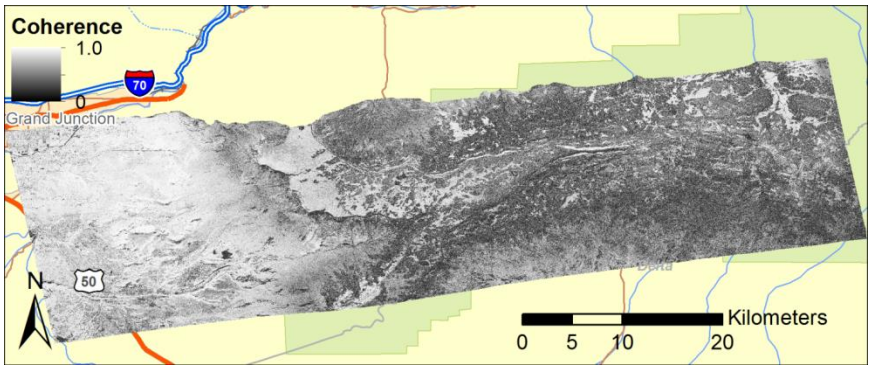


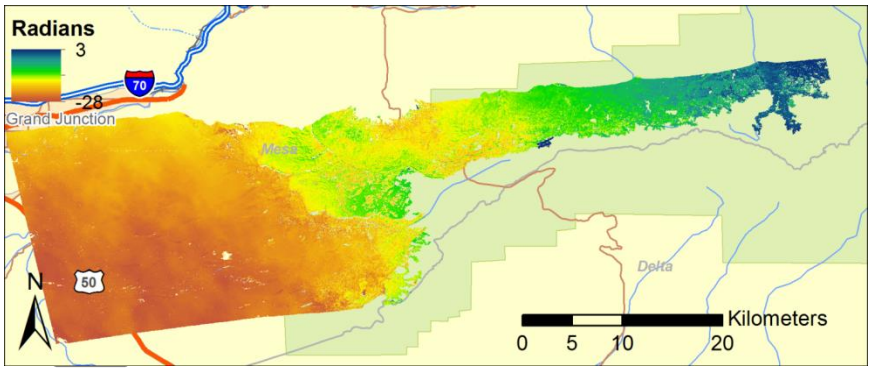
UAVSAR SnowEx Results: InSAR Products

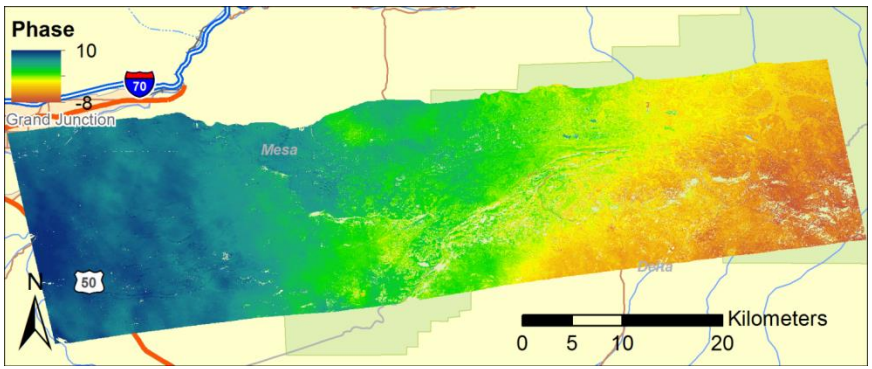




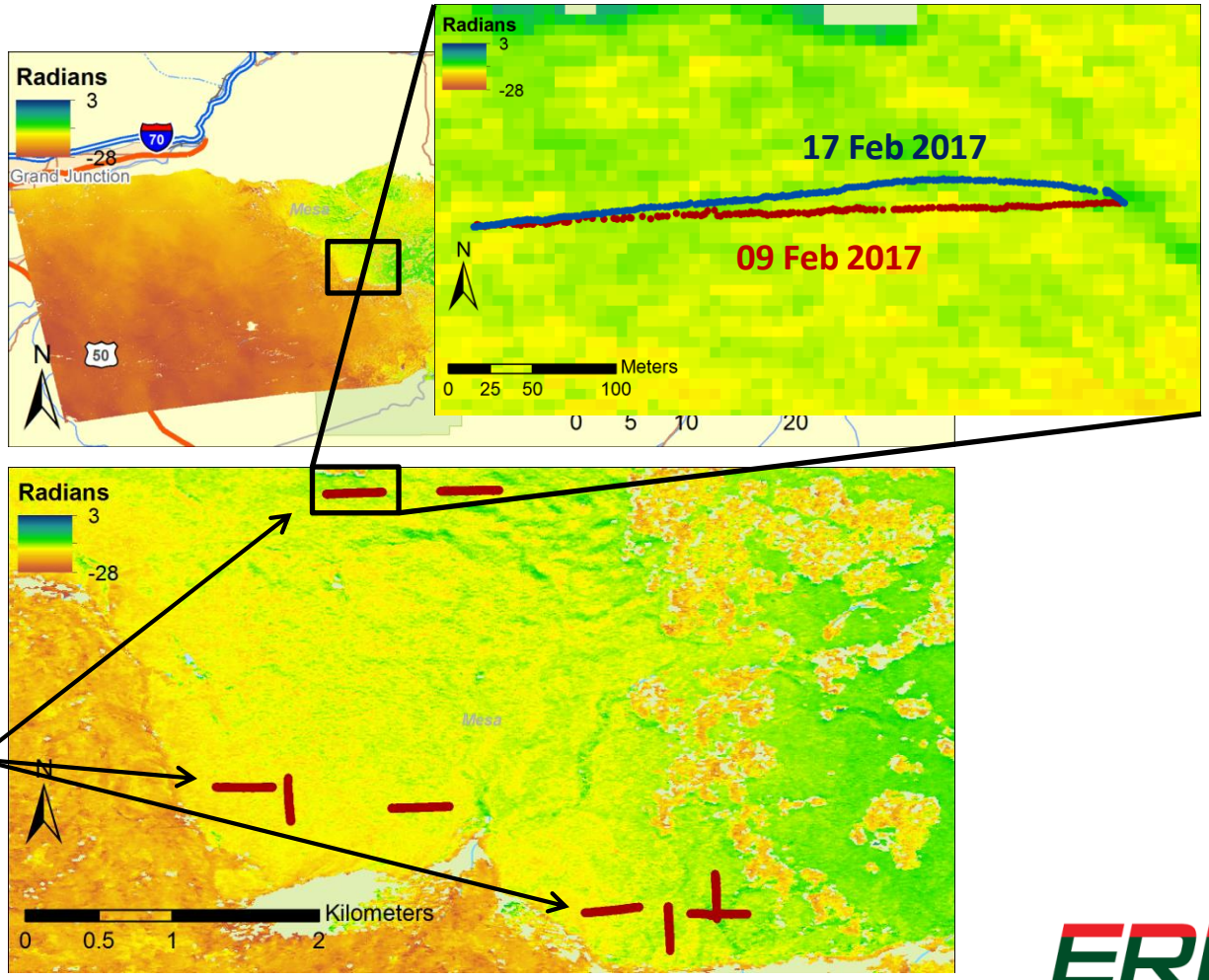








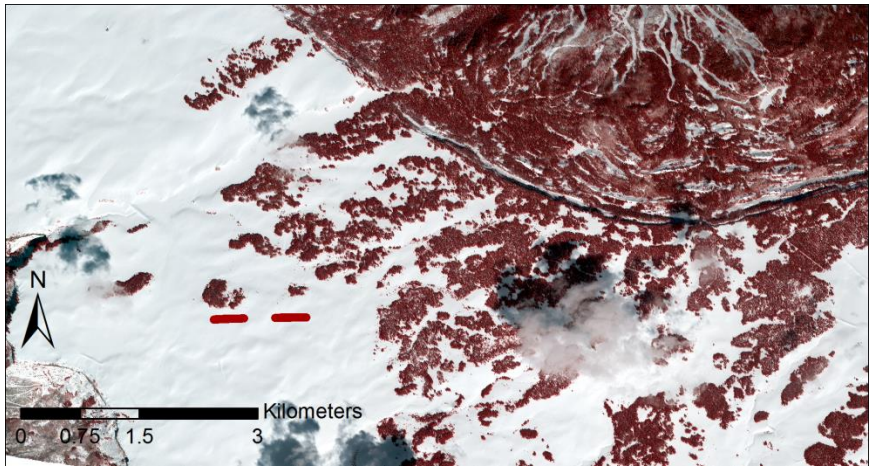
06 Feb – 22 Feb 2017 (16-day repeat)



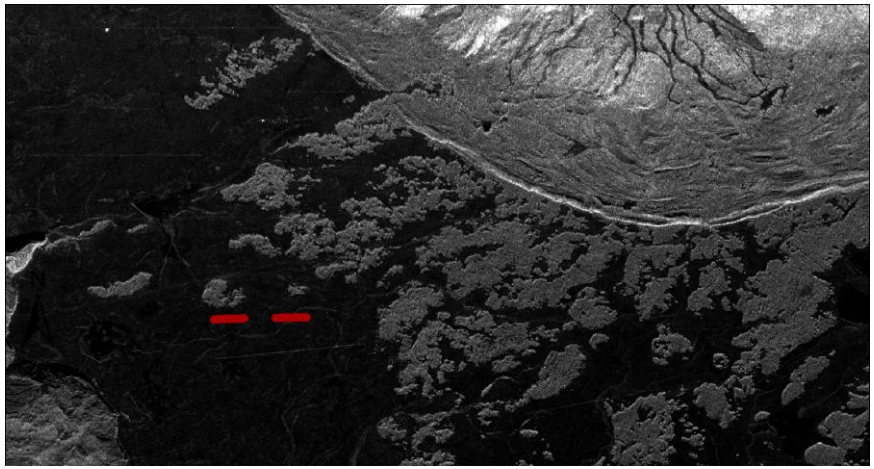
Repeated transects 09 Feb and 17 Feb

Impacts of Vegetation

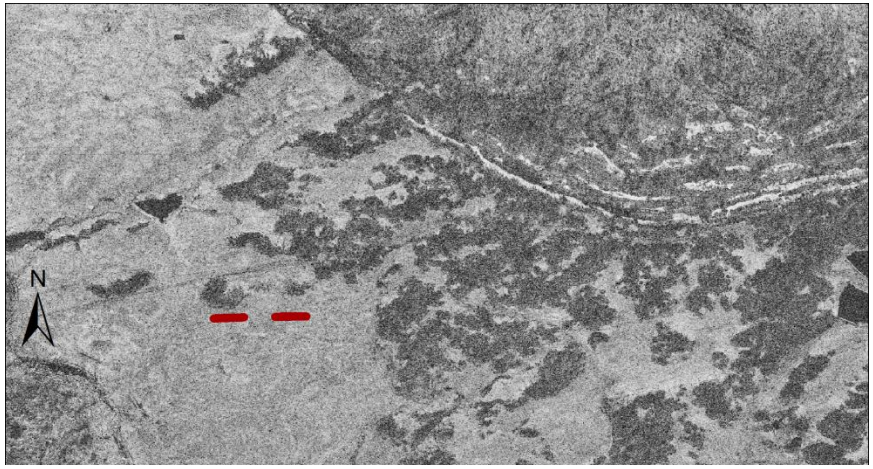
WorldView-3 (false color)



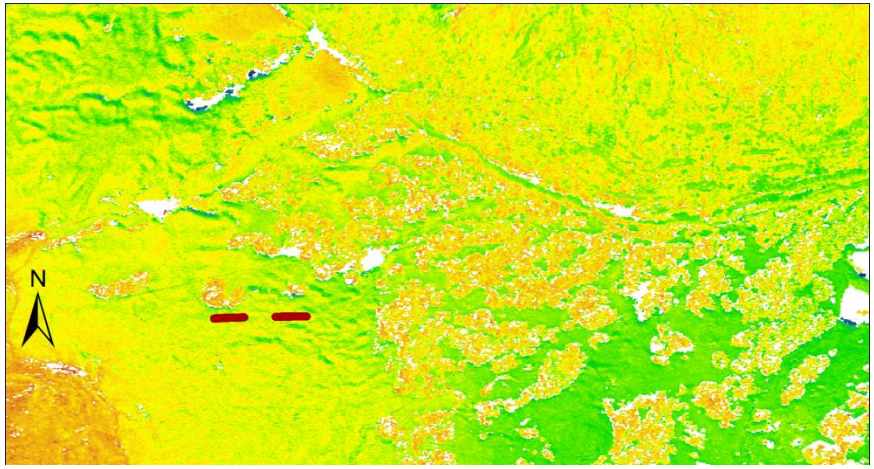
UAVSAR amplitude



UAVSAR InSAR coherence

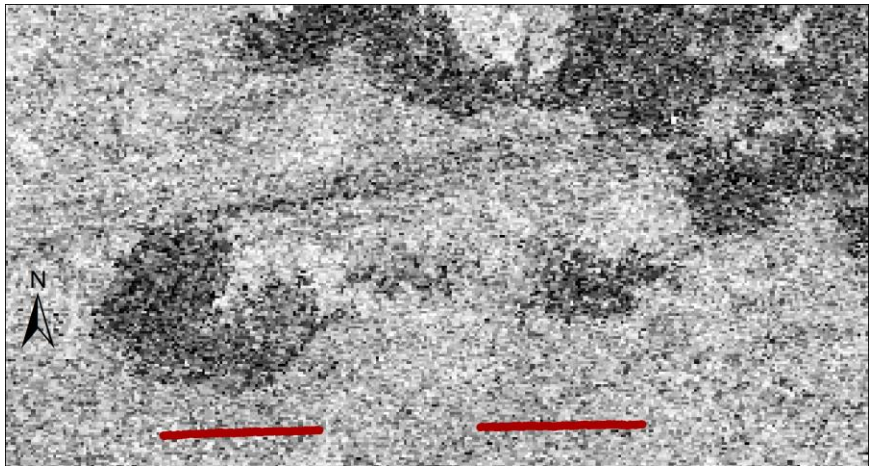


UAVSAR InSAR phase

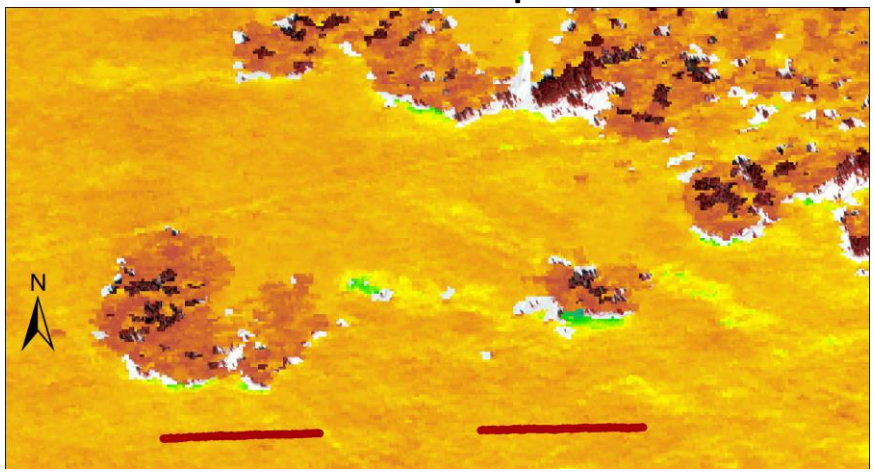


Impacts of Vegetation

UAVSAR InSAR coherence



UAVSAR InSAR phase



Next Steps

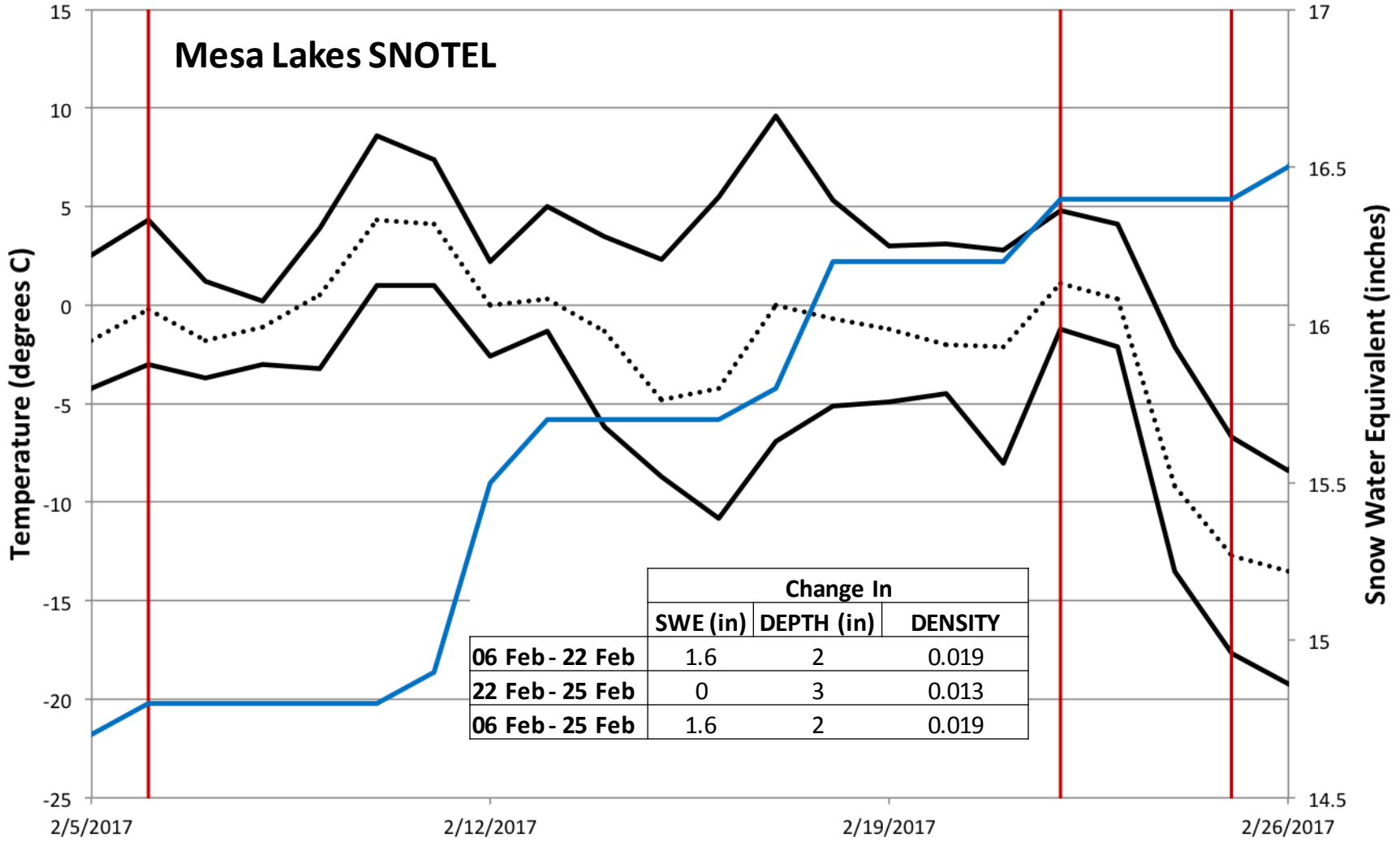
	February 2017																		
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
UAVSAR	X																X			X
ASO			X								X				X	X				X
GLISTEN-A				x											X	X				X

Table1. Logistics for airborne acquisitions of UAVSAR, Airborne Snow Observatory (ASO), and GLISTEN-A showing coordination collections around Feb. 6-9, Feb 20-22, and Feb. 25.

- UAVSAR acquisitions coordinated with Airborne Snow Observatory (ASO) and GLISTEN-A

Near Silverton, CO (Feb 2017)
Credit: Jeff Deems

General SnowEx Meteorological Obs



	Change In		
	SWE (in)	DEPTH (in)	DENSITY
06 Feb - 22 Feb	1.6	2	0.019
22 Feb - 25 Feb	0	3	0.013
06 Feb - 25 Feb	1.6	2	0.019